Study of roundwood sorting on the simulation model of longitudinal chain conveyor

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ABSTRACT

When sorting roundwood on chain longitudinal conveyors of considerable length, there is an error in moving the selected roundwood assortment to the place of discharge into the accumulator, which increases in proportion to the length of the sorting line. Currently, conveyors of limited length are used. The accumulators are located on both sides of the conveyor. This reduces the transportation error. Sometimes the sorting yard does not allow placing a short conveyor on it or there is a considerable amount of assortments. In this case, it is necessary to use a conveyor of considerable length. The paper proposes a new method of sorting roundwood on longitudinal chain conveyors of considerable length. This reduces the tracking error of the assortment movement. Angular displacement sensors of the leading and driven sprockets of the closed plate chain of the sorting conveyor are used as sensors of angular displacements. The shafts of both sensors are mechanically connected to the shafts of the driving and driven sprockets, respectively. The results of simulation modeling of the sorting control system with complex mechanical system confirmed the possibility of practical application of the proposed method to reduce the tracking error of the sorted cargo. The results of the study confirm the possibility of practical application of the device for operation on longitudinal conveyors.

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1. INTRODUCTION

Timber sorting at modern forest warehouses is one of the main types of work. Timber transporters are the most widely used in timber sorting [1]. The most important source of production efficiency growth at woodworking enterprises is the constant increase of technical level and introduction of automation means. The practical realization of these systems are reliable measuring devices [2].

At present, automatic timber sorting systems are not widespread enough. Timber sorting in a forest warehouse is one of the main types of work. However, the requirements for roundwood sorting are different [3]. Rational and fuller use of forest potential, full satisfaction of the needs of domestic and foreign markets in competitive forest products is impossible without continuous improvement of technological processes and machine systems that provide more efficient processing of timber with reduced labor and energy resources.

In the conditions of modern market economy the issues of timber assessment and accounting are of great importance. The world timber market is regulated by a system of state and interstate acts, laws and other normative documents, in particular - state standards in the Russian Federation, the EU Forest Regulations [4]–[6]. Russia occupies one of the leading positions in harvesting and export of harvested timber, the main consumers are China, Finland, and South Korea, which buy roundwood and organize its processing on their territory. At the same time, about 65% of roundwood exports fall only on China [7].

Manual sorting of timber is a labor-intensive operation. The use of automated sorting completely eliminates manual labor, reduces the number of workers and increases the productivity of timber conveyor. At automated sorting longitudinal conveyors are equipped with log throwers and command devices that provide automatic control of their work [8], [9]. Practically all contact methods of roundwood sorting have errors of measurement of movements of selected timber sorts on longitudinal chain conveyors, reaching significant values. Moreover, measurement errors of such displacements exceed the values established by domestic standards. On the other hand, all these methods are labor-intensive and poorly automated [10], [11].

In today's world, analyzing information is an extremely important task and a success factor for many industrial companies. The research methods include modeling of machine systems functioning, comparative analysis and modeling of logging efficiency indicators in assortment technology, system approach, and abstract logical methods of justification of recommendations on the choice of technological options. The problem of increasing the availability of wood resources is solved by determining the optimal routes of delivery and dispersal of loggers across territories. The latter is understood as not only economic, but also transportation, and environmental [12]–[14].

Timber sorting at modern lower warehouses is one of the main types of work. At sorting of timber, the greatest use is made of timber transporters, which belong to continuous transportation machines. Logs are transported and sorted by longitudinal sorting conveyors. The choice of sorting device is conditioned by the warehouse cargo turnover, sorting composition, sorting fraction, and conditions of timber shipment to consumers [15]–[18].

When sorting logs on longitudinal chain conveyors of considerable length, there is an error in moving the selected log assortment to the point of discharge into the accumulator, which increases in proportion to the length of the sorting line. At present, conveyors of limited length are used. The accumulators are placed on both sides of the conveyor. In this case, electric drives that use an electric motor as the primary motor are used and are considered the best solution to the problem of transferring energy from the source to the point of consumption and converting it into its final form [19]. This reduces transport errors, sometimes the sorting site does not allow the installation of a short conveyor with double-sided unloading, or it is necessary to sort a large number of forest species. In this case, it is necessary to use a longer conveyor. In the article, the authors propose a control device for sorting logs on longitudinal chain conveyors of considerable length. This reduces the tracking error of the assortment movement along the conveyor [20], [21].

In this paper, we consider a roundwood chain conveyor with a sorting zone of considerable length, more than 200 m, and the length of the conveyor itself is correspondingly longer, e.g. 225 m. The last storage unit, for example, is located at a distance of 15 m from the leading tourer, and the sorting zone from the control panel to the last storage unit is 200 m long. There is 10 m for the slave tourer to load the chain conveyor and to position the means for evaluating the geometric dimensions of the logs and their quality properties. If a link of the plate chain conveyor has a size of 200 mm, the number of chain links will minimally amount to 1125 pieces. Modeling the motion of such a number of links in the mechanical system of the conveyor is very difficult or impossible due to the limitations of the software product MATLAB R2021a [21], [22].

In connection with the above, the accuracy of roundwood sorting affects the efficiency of sawmill production in general, there is a need to create new approaches and methods of sorting timber in the timber industry, taking into account the automation of the technological process [23], [24]. Therefore, the task is set related to the development and research of a roundwood sorting device to minimize the error of moving the roundwood assortment on a longitudinal conveyor to the selected address when delivering the cargo to the storage bunker.

This paper introduces a new concept of a model link for the transporter, including 75 chain links, with a length of $75\times0.2=15$ meters. The mass of the model link is approximately 500 kg. The five-model links are joined together by couplers to form a section with a length of 75 meters. By means of the couplers, it is possible to enter the equivalent gap between 75 links of the flat plate chain into the model. The three upper-level sections make it possible to make a conveyor model 225 meters long. Three lower-level sections are needed to close the conveyor chain into a continuous ring. The tractive forces required to move the model links must be measured and summed. The full load is applied to the traction motor.

2. METHOD

The mathematical model in operator form of a rotating coordinate system with arbitrary frequency ω_k for vector-controlled electric drive, which is the basis for the description of the electromechanical system of a sorting conveyor, is given in the literature [25]. In this case, the frequency converter control system provides orientation of the rotor flux-coupling vector Ψ_{RNOM} along the *x*-axis of the rotating coordinate system, as in (1).

$$\Psi_{RNOM} = \Psi_{Rx}, \Psi_{Ry} = 0 \tag{1}$$

The rotor flux $\Psi_{RNOM} = \Psi_{Rx}$ is oriented along the *x*-axis if the frequency of the inverter ω_i (current source) corresponds to the rotational frequency of the coordinates ω_k and the required frequency of the current source ω_i is determined by the rotor speed ω_m, stator current i_{Sy} and rotor flux Ψ_{Rx}. The drive is controlled by setting the stator current in the respective axes. The x-axis specifies the stator current component, which determines the stator flux, and the y-axis specifies the current component, which determines the motor torque [25].

In addition, the current values of the y-axis current and rotor flux determine, together with the rotor speed, the frequency of the inverter supplying the motor. It should be noted that in this paper we consider the frequency-current control, which has astatic regulators included in the feedback circuits of the stator current components, which allow us to avoid static error when working off the disturbing influences in the system. Thus, the standard frequency-current control is reduced to a form that allows us to approach our system under study to a regulated direct current (DC) electric drive with an independent excitation channel, which increases the accuracy of delivery of sorted cargo on the timber conveyor to the discharge point.

To carry out the research, a model of a round wood sorting conveyor has been developed on the basis of MATLAB R2021a software product. The scheme of the developed model "Model_sort_trans.slx" is presented in Figure 1 and includes three blocks: "Transporter", "Control Unit", "Control Channel", and two different sources of random numbers: "Uniform Random Number1" and "Random Number" to generate a random variation of the linear speed of the chain on the driving and driven sprockets from all possible factors. The speed variation range is ± 20 % of the conveyor speed of 1 m/s.

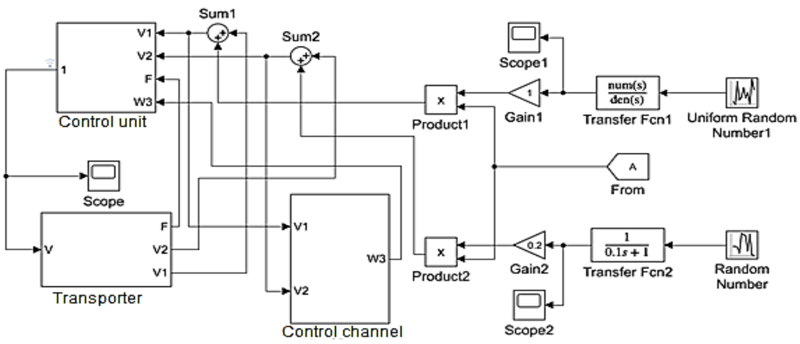

Figure 1. Model diagram "Model_sort_trans.slx"

The scheme of the model of the "Transporter" block is shown in Figure 2, and the model realization is performed on the elements of SIMULINK and Simscape libraries. Harmonization of signals, combining inputs and outputs of elements of both libraries, is carried out with the help of additional elements such as "Simulink-PS Converter" and "PS-Simulink Converter". Sections 1.1-1.3 in Figure 2 in the initial state of the model are at the upper level of the transportation system, and the elements of sections 2.1 - 2.3 at the lower level. Each element of the section passes through all levels of the transport system during the modeling process. The speed of conveyor movement is set by input v from the control unit. The Sum1 adder receives two signals: from the input v and the random number source "Uniform Random Number1", which leads to simultaneous change of speed of all sections and model links of all levels.

Random interference does not lead to control errors during log sorting. If you increase the amplitude of interference from the source "Uniform Random Number1", then the signal from the output of Sum1 is converted by the element "Simulink-PS Converter" into the signal format of the library "Simscape" and comes to the input of the source of linear velocity "Ideal Translational Velocity Source", which sets the specified speed of movement of all moving masses of the transport system. The block "Solver Configuration" (similar block in

Simulink element library - "powergui") and the element "Ref VS" are necessarily used in the realization of the block "Transporter". The contents of the model scheme "Transporter Section" is shown in Figure 3.

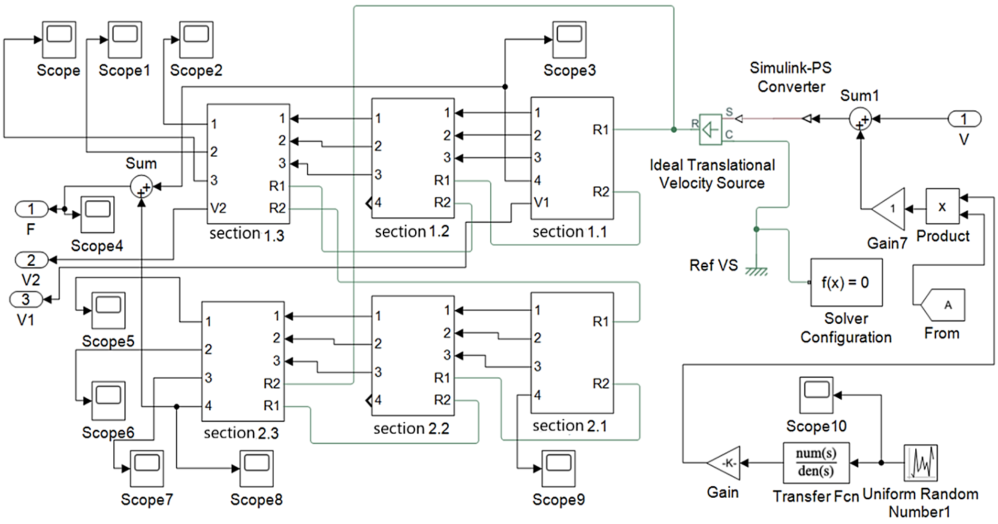

Figure 2. Schematic diagram of the "Transporter" block model

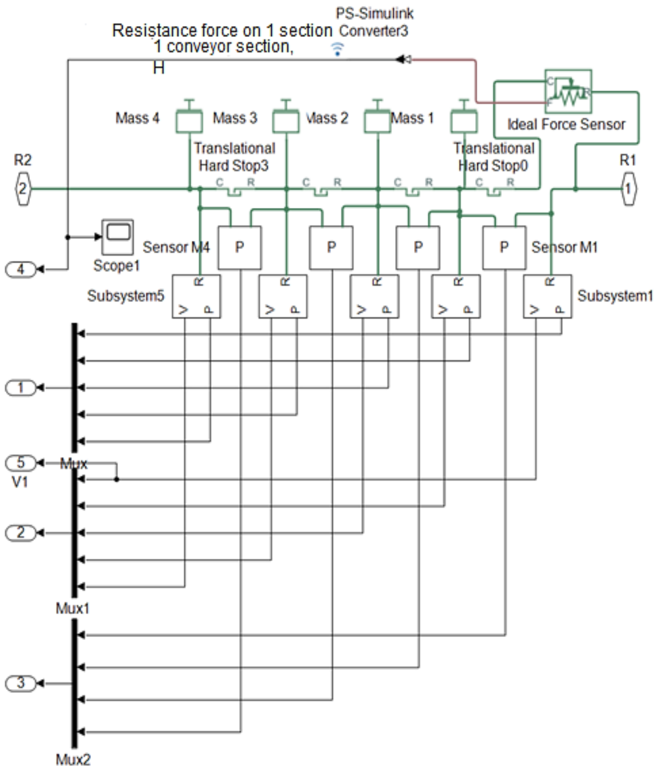

Figure 3. Block model diagram "Conveyor section"

The main element of the scheme is Mass 1 - Mass 4. The physical basis of the masses are the 15 m long sections of the conveyor chain (75 chain links of 0.2 m length), which have been called model links. The mass value of a model link is assumed to be 500 kg and requires more complete justification. The masses are connected by "Translational Hard Stop" couplings, the parameters of which are the clearances and mechanical characteristics of the material involved in the transmission of the required force for the conveyor movement. The gap value is set to ±0.025 m (±25 mm).

Consequently, the clearance per link of the real chain is ±25 mm/75=±0.33 mm. The force acting on the hitch is measured by the Ideal Force Sensor. It should be noted that the force required to move not only this section, but also all other sections connected to the output of this section R_2 is measured. Sensors P "Sensor M" are designed to measure the coupling gap or real gap - gap position - in 75 links of the model link chain. Elements "Subsystem1 - Subsystem5" are designed to measure the speed and position (position) of moving masses. The element is based on the position and linear velocity sensor "Ideal Translational Motion Sensor" and is shown in Figure 4.

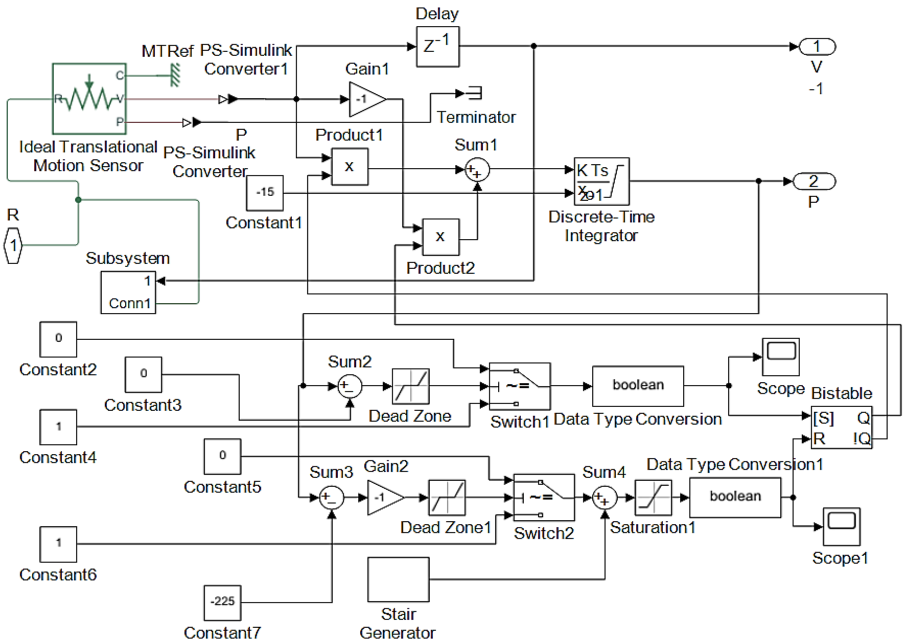

Figure 4. Subsystem sensor for speed and position of the moving mass of the model link

However, it is not possible to use the position signal P of the sensor, because when the velocity of the conveyor is unchanged in the direction, the links of the lower level go backwards in position due to the design of the transportation system. Due to this fact, a Subsystem element has been developed, the model schematic of which is shown in Figure 4. The linear velocity of the moving mass of the link is measured by the Ideal Translational Motion Sensor. The position of the link is modeled by the "Discrete-Time Integrator". To work out the return movement of the link, a fictitious negative speed of the conveyor is formed on the element "Gain1". The direction of movement is set by a logic element with memory trigger with R, S control. The trigger Q output connects the positive sign conveyor speed to the "Discrete-Time Integrator" input. The trigger Q output connects the dummy negative sign conveyor speed to the "Discrete-Time Integrator" input. The logic signal "1" on the input R puts the trigger in the state: $Q =, \bar{Q} = 1$. Logic signal "1" on input S puts the trigger in the state: $Q = 1$, $Q = 0$. With the beginning of modeling the initial output voltage of the integrator is set in accordance with the initial position of the model link under consideration, which is set in meters from the output of the element "Constant1".

In this case, Figure 4 considers a model link located at the position "minus 15 meters" to the leading tourer. In addition, at the initial moment of modeling the element "Stair Generator" generates a signal with duration of 0.1 s, which puts the trigger "Bistable" in the zero state, i.e. one from the output Q goes to the multiplying element "Product1" and connects the positive speed of the transporter v through the adder "Sum1" to the input of the integrator "Discrete-Time Integrator". The output voltage of the integrator starts to grow from minus 15 meters to zero, which corresponds to the movement of the model link from the position of minus 15 meters to the leading sprocket.

When the level set by the output voltage of the "Constant 3" element is reached, the "Switch 1" element and the "Bistable" trigger are switched. The input of the integrator "Discrete-Time Integrator" receives a negative rate through the multiplying element "Product 2". The output voltage of the integrator becomes negative and increases in the negative direction. This means that this model link has reached the position of the leading tourer, reversed, and started moving in the reverse direction without reversing the speed of the conveyor. As soon as the integrator output voltage reaches the value set by the "Constant 7" element - "minus 225", the "Switch 2" switch is triggered and a signal appears on the R input, putting the trigger in the zero state, which switches the integrator input to positive speed and the integrator output voltage will change from minus 225 m to zero. Physically, this means that the model link has reached the slave tourer position and has changed its direction of travel to the master sprocket. The schematic of the Subsystem block model is shown in Figure 5.

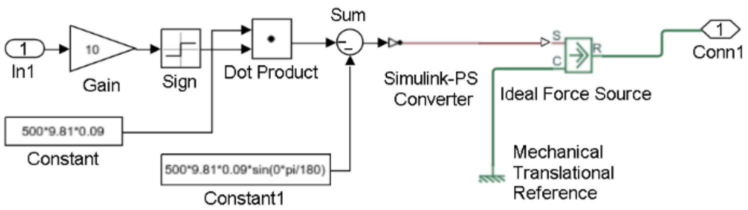

Figure 5. Schematic diagram of the model of formation of the force of resistance to movement of the model link

In the "Constant 1" block there is a formula for determining the drag force of the model link with mass 500 kg, g = 9.81 m/s^2 - acceleration, friction coefficient μ=0.1. The resistance force FC has a reactive character, so the element "Sign" controls the speed of the model link. At zero velocity $F_C = 0$. In the block "Constant 1" the formula for determining the active component of the drag force arising from the deviation of the motion trajectory with respect to the horizon is recorded. The deviation in degrees is entered into the sine formula instead of zero.

The negative signs in the summation "Sum" follow from the formulation of the law of motion, as in (2).

$$F - F_C = M \times a \tag{2}$$

Where M is the mass and a is acceleration of the moving mass. At the steady motion of the mass a = 0, $F = F_C$. All these mathematical transformations are performed by the "Mass" block from the Simscape library. In conclusion, of consideration of blocks of the "Transporter section" type it should be noted that blocks "Section 2.1" - "Section 2.3" in Figure 2 have a changed structure of control of the model block. In the blocks "Subsystem" - "Subsystem4" in the specified sections the control structure of the trigger "Bistable" has been changed, as shown in Figure 6.

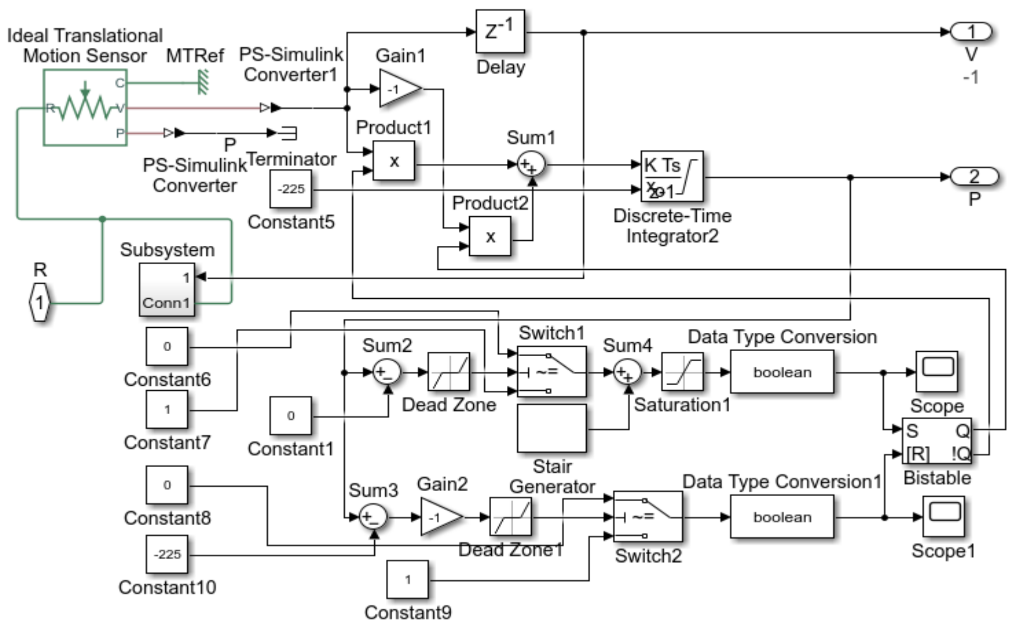

Figure 6. Schematic diagram of the Subsystem block model

The modeling start signal generated by the "Stair Generator" block sets the "Bistable" trigger to the single state and the integrator output voltage starts to change to the value of minus 225 m. Physically it means movement of the model link towards the slave tourer. When the minus 225 m mark set by the "Constant 10" element is reached, the "Switch 2" element is triggered and sets the trigger to the zero state with its output signal. The positive speed is connected to the integrator input and the integrator output voltage starts to increase from the value of minus 225 m to zero. When the output voltage is zero, the "Switch 1" element is triggered, the integrator input voltage changes sign and the integrator starts to produce a negative output voltage.

3. RESULTS AND DISCUSSION

To study the operation of the roundwood sorting conveyor, a model of the control unit of this conveyor has been developed based on the MATLAB R2021a software product and is presented in Figure 7. The main element of the block is the model of traction asynchronous electric drive. Starting of the drive is carried out by direct switching of the motor "Asynchronous Machine SI Units" into the network. The model of power supply and starting equipment is represented by the block "Subsystem1". A three-phase RL circuit "Three-Phase Series RLC Branch" is introduced to take into account the parameters of the real network: supply transformer and power cable. The "Three-Phase Series RLC Branch1" shunt resistor blocks the self-induction EMF when the motor is disconnected from the main supply. Reactive drive operation is only possible with the "Subsystem2" mechanics block, which is specifically designed for use in MATLAB R2021a with motors of any type and power.

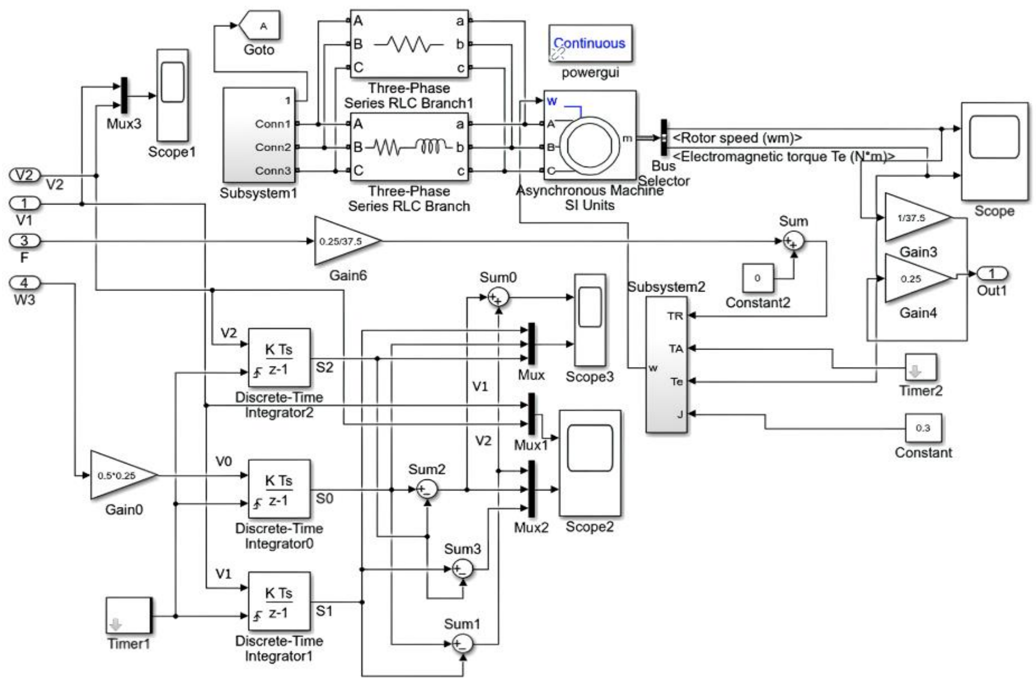

Figure 7. Control unit model diagram

The force for the conveyor movement, defined in the "Conveyor" block, is input F, converted into the resistance torque (Nm) by multiplying it by the coefficient (0.25/37.5), where the radius of the sprocket is 0.25 m, 37.5 is the reduction factor between the motor shaft and the shaft of the driving sprocket. The resistance torque is fed to the adder "Sum" and then to the TR input of the mechanics unit "Subsystem 2". If additional mechanical losses are taken into account, they are input by the second input of the "Sum" adder.

Setting the linear speed of the conveyor is carried out by the chain: rotor speed ω_m, reduction ratio "Gain3", tourer radius "Gain4", output port "Out1". The diagram of induction motor starting is shown in Figure 8. The motor was started at a speed of 153.2 1/s with a load of 88.12 Nm. At the moment of start-up, the pulsations of speed and torque associated with the connection of model links can be seen in Figures 9(a) and 9(b).

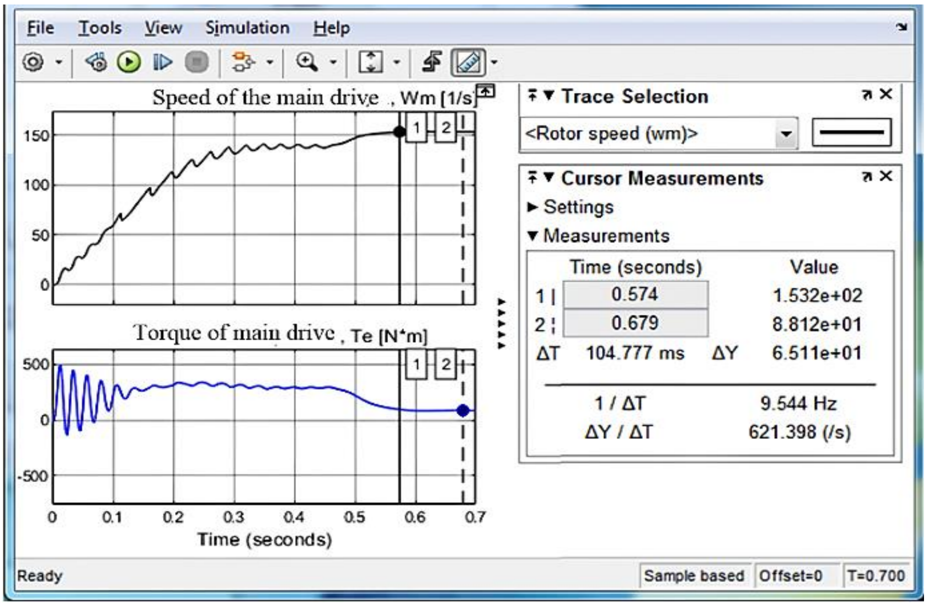

Figure 8. Speed and torque diagrams for induction motor

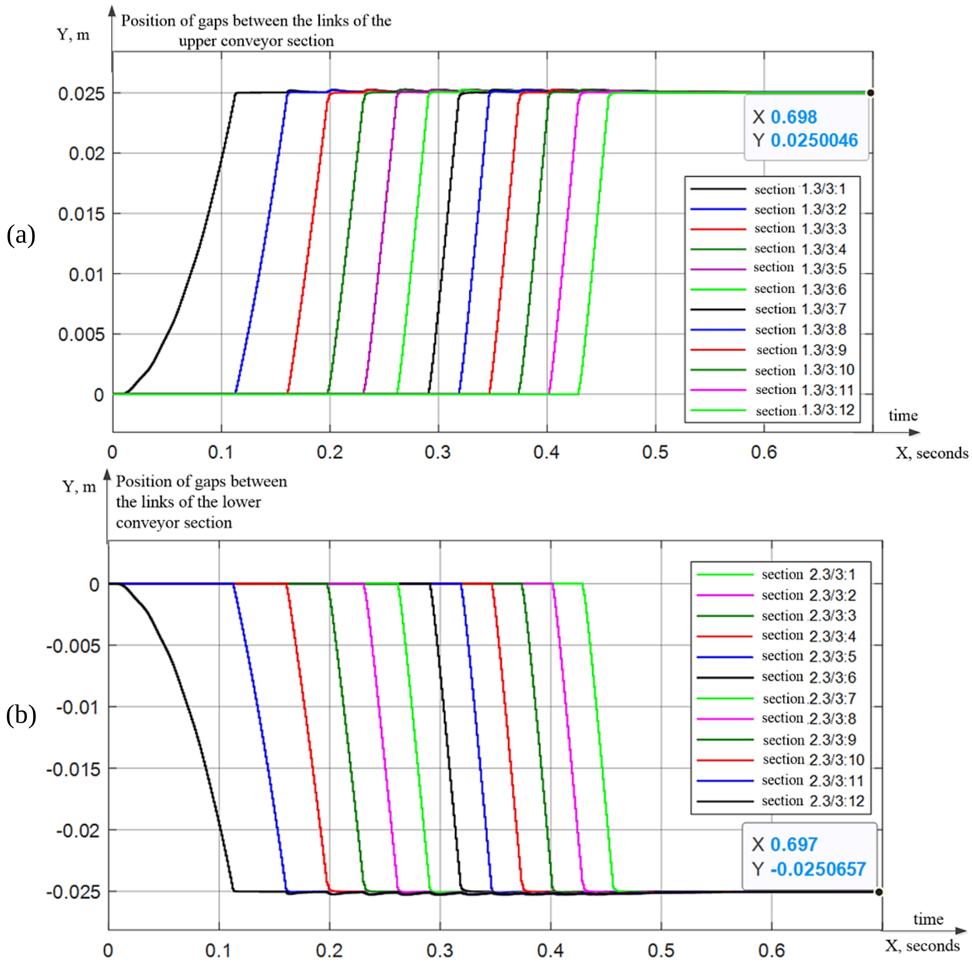

Figure 9. Diagrams of clearances between links during the start-up of the conveyor belt:
(a) diagrams of the gap positions between the links of the upper conveyor section and
(b) diagrams of the position of the clearances between the links of the lower conveyor section

Figure 9 shows the diagrams of the state of gaps between the model links during the start-up of the conveyor. Figure 9(a) shows a diagram of the clearances between the links during the start-up of the conveyor for the position of the upper conveyor section. Figure 9(b) shows a diagram of the clearances between the links during the start-up of the conveyor for the position of the lower conveyor section. During the start-up of the conveyor, the upper section of the conveyor system is lengthened by 300 mm due to gap selection, and the lower section is shortened by 300 mm due to gap compression. The total length of the conveyor remains unchanged. In real conditions, it may happen that the tensile and compression gaps are not equal.

In order to prevent emergencies with the conveyor chain and sprockets, a tensioning station is provided to prevent sagging of the lower section of the conveyor system or overstressing of the links during tensioning, thus avoiding chain breakage. The main disturbance is the variable load, which is particularly adverse on long conveyor lengths. The diagrams in Figure 10 show the dynamic effect of gap switching on tractive effort. Figure 10(a) is a diagram showing the force resisting the movement of the upper conveyor section. Figure 10(b) is a diagram showing the force of resistance to conveyor movement.

The maximum contact force is 25 times higher than the operating force. This leads to an increase in the strength and cost of the conveyor chain. In order to reduce the amplitude of contact forces, it is necessary to select clearances at low speed and then to reach the working speed. Practically, this leads to the necessity of using an adjustable electric drive. In addition, the control unit provides an estimation of the control accuracy without the use of sprocket (tourer) speed measuring devices (ideal case).

(a)

(b)

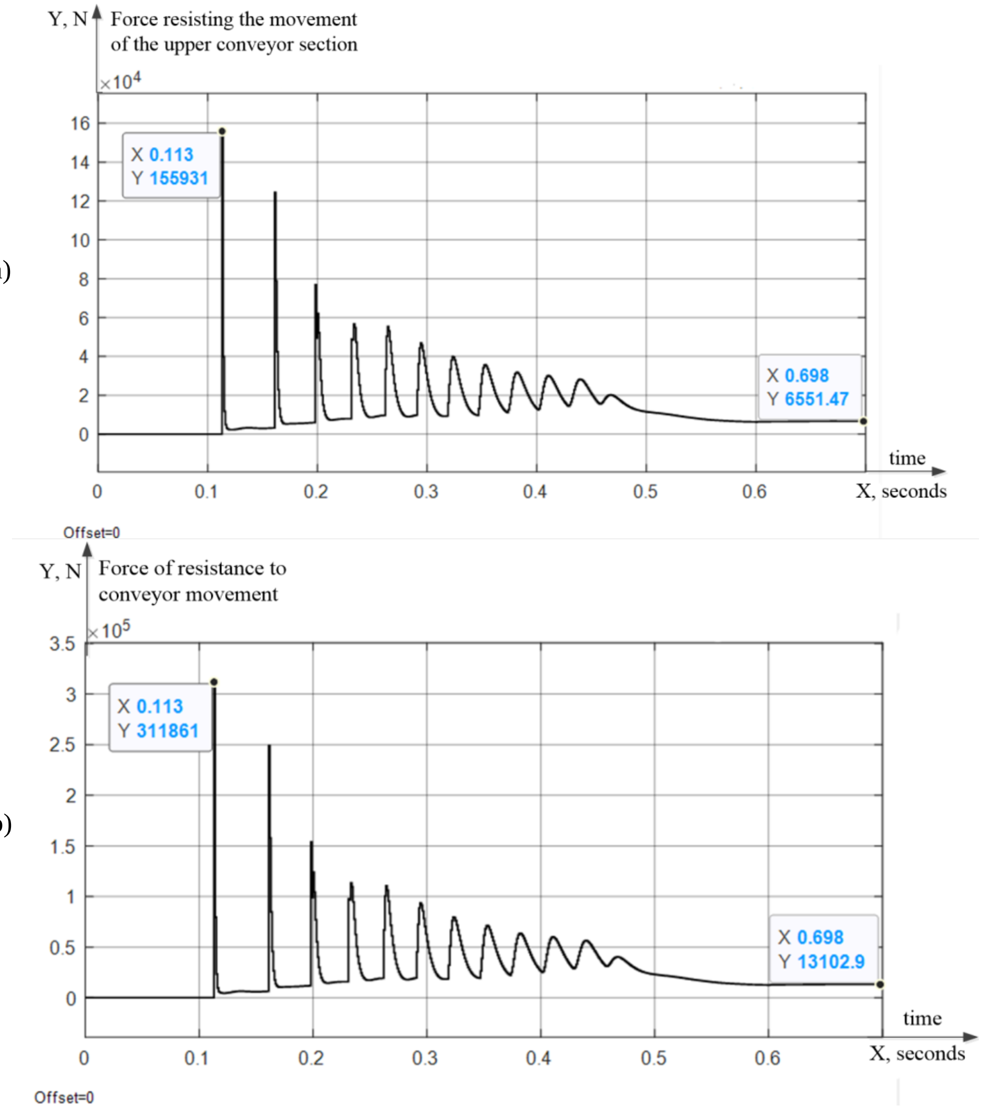

Figure 10. Forces on conveyor links during conveyor start-up: (a) force resisting the movement of the upper conveyor section and (b) resistance force to conveyor movement

Figures 11 and 12 show the diagrams of sorting control errors for different ways of forming the control channel and the diagram of control error when forming the information (control) channel from the sum of speeds of the master and slave sprockets. An analysis of the diagrams in Figure 11 shows that there are sorting control errors. A particularly illustrative example is the control from one of the sprockets. The control error recorded by Sum3 (Figure 11) when the conveyor was moved only 20 m (10% of the maximum sorting length), was the highest value of about 0.15 m. At the same time, it should be remembered that the necessary measurements were made under ideal conditions. In the same conditions, the estimation of the control error of the proposed method of formation of the information channel (half of the sum of the speeds of the driving and driven sprockets, is shown in the diagram of Figure 12 "Sum0". The error recorded in the modeling process was zero with a high degree of accuracy.

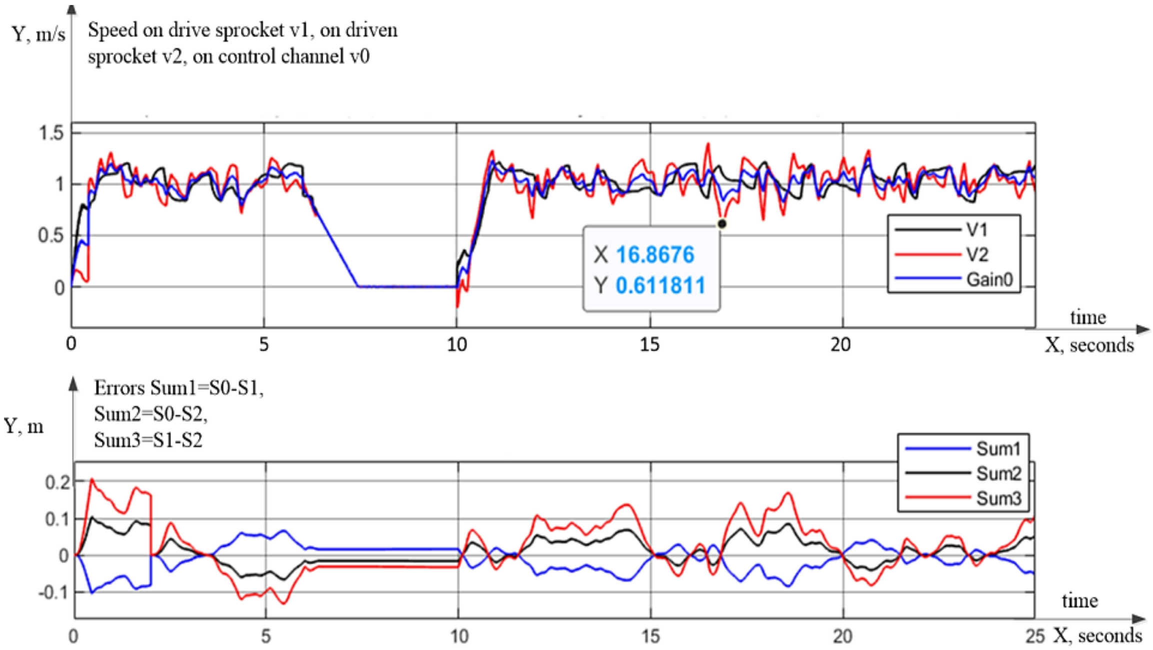

Figure 11. Sorting control error diagrams for different methods of control channel formation

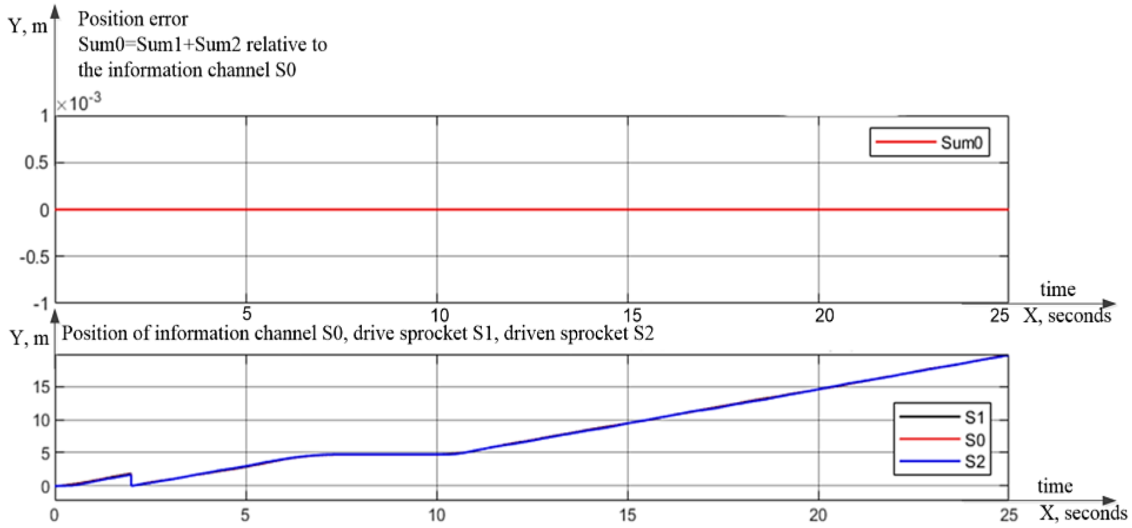

Figure 12. Diagram of control error when forming information (control) channel from the sum of driving and driven sprocket speeds

4. CONCLUSION

The proposed device for sorting roundwood can be used when sorting wood trunks by species and has the possibility of reducing the error of tracking the movement of roundwood to the appropriate storage bunker, allows to increase the accuracy of the formation of control commands to dump roundwood in the storage tanks due to the synchronization of the movement of information about its movement relative to the storage tanks in the sorting control device; provides the possibility of scaling the movement of information on the movement of roundwood.

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